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Design and Application of a Spray Rinsing System for Recycle of Process Waters

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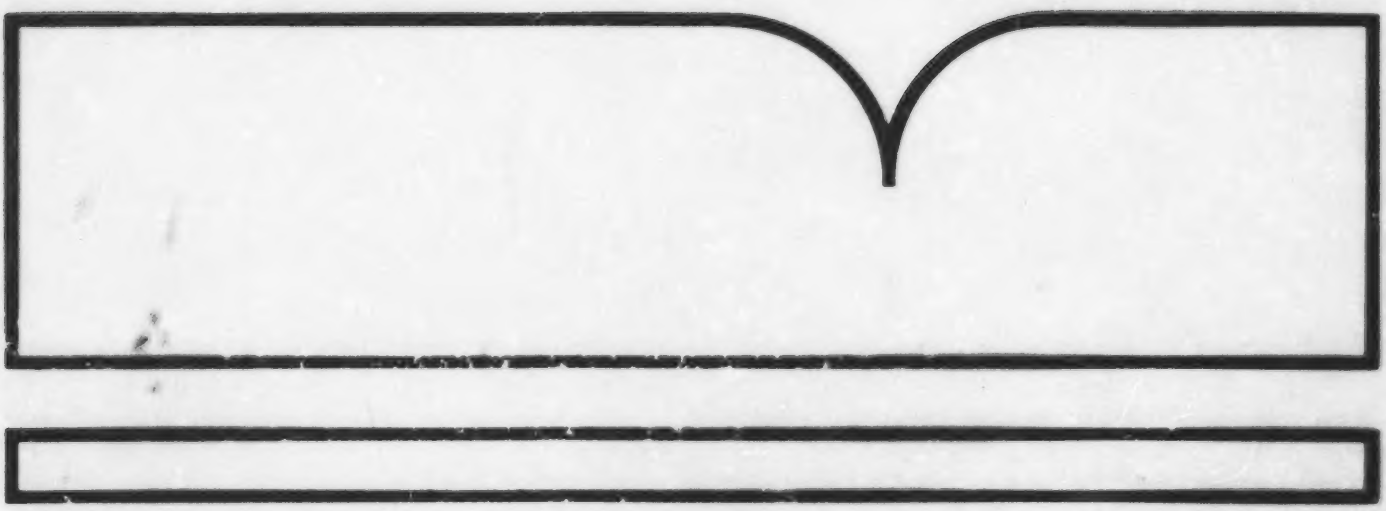

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16. ABSTRACT

This research demonstrates the effectiveness of an innovative application of a multiple spray rinsing system in an electroplating process. A joint study was conducted by NCR and the U.S. EPA at NCR's printed circuit board facility in Cambridge, Ohio. Engineering evaluations were performed to assess and compare the water usage requirement, chemical needs, material recycle capabilities, and the effluent treatment and disposal requirements of the spray rinse system to those of the Napco shuttle dip rinse system previously used. An economic analysis was also performed to determine the annual differential costs of the old and new rinse systems with respect to reductions in water and sewer, chemical, effluent treatment, and sludge disposal costs.

The results of this study indicated that utilization of the spray rinsing system in place of the previously used dip rinsing operation reduced operating costs without sacrificing rinse efficiency. Water usage was decreased by approximately 90 percent and 94 percent of the nickel metal was recovered and returned to the plating bath. A substantial savings in treatment and disposal costs was also realized through the isolation and concentration of the nickel metal and subsequent reduction in sludge volume of hazardous materials. Joint participation in this research effort has proven to be successful for government and industry's quest for a better environment while producing substantial cost savings.

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INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has defined the electroplating industry as that portion of industry applying coatings on surfaces by electrodeposition (1). Pretreatment and postplating operations are included and are carried out by both independent (job) platers and captive shops, i.e., facilities plating their own work. Approximately 13,000 companies are engaged in metal plating in the United States (2).

Rinsewaters constitute one of the largest sources of pollution in an electroplating operation due to their large volume and low metal concentration. Results from a recent Cleveland survey (3) showed that the average rate of rinsewater discharged to the Publically Owned Treatment Works (POTW) from 22 area electroplating shops was approximately 18,500 gpd in comparison to 60 gpd resulting from spent process solutions. The discharge of these rinsewaters not only results in increased treatment and disposal costs but also in increased process costs due to loss of valuable chemicals. These economic considerations, as well as the regulatory requirements placed on the metal finishing industry in the past decade, have brought several pollution control and treatment technologies to the attention of the plating community. Many of these technologies are "black boxes" with high capital and operating costs and unproven long-term performance. An operator with a sound working knowledge of engineering and/or chemistry is often required to keep the unit in operation. In many instances the installation of such a technology results in an unacceptable payback period and little if any return on investment for the plater.

Joint research and demonstration efforts by the EPA and the metal finishing industry (3,4) have shown that substantial cost savings can be achieved in electroplating operations through the implementation of in-plant changes, particularly those aimed at minimizing dragout (i.e., the solution that adheres to objects when removed from a bath) from process solutions and reducing the quantity of water used in rinsing operations. This paper shows how cost savings and improved environmental control and high rinse efficiency can be achieved by reducing the quantity of water used in rinsing operations.

Background

A joint research project was undertaken by National Cash Register Corp. (NCR) and the U.S. EPA's Industrial Environmental Research Laboratory, Cincinnati, Ohio, to demonstrate the effectiveness of a multiple spray rinsing system designed by NCR and installed on the company's nickel electroplating line at their printed circuit board facility in Cambridge, Ohio. Engineering evaluations were performed to compare the water requirements, chemical needs, material recycle capabilities, and the effluent treatment and disposal requirements of the spray rinsing system to those of the Napco shuttle dip rinse system previously used. The Napco shuttle used in this application consisted of a horizonal-flow rinse tank (approximately 30 ft. x 1 ft. x 5 ft.) in which water flow was countercurrent to the direction of the rack. An automatic overhead hoist was used to raise and lower the loaded rack and transport it across the shuttle. An economic analysis was also performed to determine the annual differential costs between the old and modified rinse systems with respect to reductions in water and chemical costs, effluent treatment, and sludge disposal costs. The objectives of this project included: (1) determination of the rinsing efficiency of the modified rinse system in comparison to that of the old, (2) assessment of the water usage reduction potential of the modified rinse system operated under normal operating conditions, (3) determination of the quantity of nickel metal recovered for reuse, and (4) comparison of the associated economic costs and benefits of the modified rinse system to those of the old system.

This project was a part of an environmental program in force at NCR, Cambridge, Ohio. The NCR program includes among its objectives the isolation, separate treatment, and filtration of chelating agents, complexing agents and nickel salts, and a significant reduction in rinse waters. After implementation of many techniques such as stagnant rinses, cascaded rinses, and conductivity controllers, it was recognized that the water efficiency of the Napco shuttle dip rinse system was limited to what could be achieved by dilution. Initial testing results with a scaled-down prototype unit demonstrated that the spray rinsing system offered several advantages over the dip rinsing method. The primary advantage of the spray system is its ability to remove a substantially greater quantity of metal from within the holes in the printed circuit board as well as from the surface of the board. Since bench-scale testing further showed that this improvement could be achieved together with a reduction in water usage greater than 90 percent, the spray rinse system was scaled up and installed on an active plating line for further evaluation.

The Printed Board Production Process

Printed circuit (PC) boards consist of nonconductive board material onto which a circuit pattern of conductive metal (primarily copper) has been formed. The board provides a surface for the application of a conductive wiring path and supplies support and protection for electrical components to be connected by the board circuitry (5). In general, there are three types of PC boards: single-sided, double-sided, and multilayered. The type of board used depends on such things as spacial and density demands, and intricacy of the circuits required (6). When relatively simple circuitry is required and circuit types and speeds do not place unusual demands on wiring and electrical characteristics, single-sided boards are usually used. If density demands require more than one layer of wiring, circuits are printed on both

sides of the board and the interconnection between the layers is made by going through the board rather than around it. In this case, the connection is generally made by plating a conductive metal (usually copper) inside holes drilled through the board. This process is usually referred to as plating-through-holes . Multilayered boards are used when increased wiring density is required. The manufacturing of multilayer boards involves the addition of several inner layers of individual circuit boards bonded together by an epoxy glass material. Multilayered boards are usually built up to six layers thick for applications in electronic business machines.

Three main production methods (additive, semiadditive, and subtractive) are utilized by the printed board industry in the fabrication of printed circuit boards. The additive production method involves the deposition of plating material on the board in the pattern dictated by the circuit, rather than removing metal already deposited (as in the subtractive process). The semiadditive process is a compromise between the additive and subtractive methods.

As part of its daily operation in Cambridge, Ohio, NCR produces approximately 6000 square-feet of double-sided and multilayered printed circuit boards for electronic business machines using the additive production process. In this process (5), fiberglass boards are initially covered with a copper foil, drilled, and mechanically sanded. A rack panel plating line employing electroless copper and electrolytic copper is utilized in the next step, plating-through-holes. In this process palladium and tin are deposited on the surface of each board as well as on the inside surface of each hole. Electroless copper is then applied on top of the palladium and tin, and continuity is established. A resist film (usually a light sensitive polymer) is applied to the boards followed by the application of an ultraviolet light source through a pattern onto the resist. After activation, the unexposed resist is chemically dissolved leaving the desired circuit diagram imprinted on the surface of each board. The boards are then reloaded onto racks and passed through a pattern plating process utilizing electrolytic copper and electrolytic nickel. The copper electroplate is deposited to build the circuit to the desired thickness, while the nickel provides a protective coating. After the nickel electroplate has been applied, the boards are rinsed via NCR's new spray rinsing system. Following the rinse, and if the application requires it, a gold electroplate is deposited and the boards are rinsed again. The boards then undergo an etching process to remove the excess copper, and a solder plate is applied to each board to seal the copper circuit and to protect it from corrosion after final fabrication. The boards are then subjected to a final inspection.

ENGINEERING DESIGN OF THE SPRAY RINSE SYSTEM

The engineering design of the new multiple spray rinse system required the modification of an existing Napco shuttle dip rinse system. A parallel rinse tank arrangement using two tanks, the shuttle with a volmetric throughput of 3.5 gpm and an overflow rinse tank with a flow of 1.5 gpm, comprised the dip rinse system. Construction of the new system required the installation of a polypropylene liner in the shuttle. The liner was divided into three compartments by vertically positioned baffles as shown in Figure 1. Lower baffles were extended to the maximum height possible to permit the rack to pass through the shuttle unimpeded. Side baffles were also installed to minimize overspray between the compartments. A total of 56 Vee jet spray nozzles

which were vertically mounted on the sides of the shuttle liner in the second and third compartments.

After exiting the nickel bath, the loaded rack vertically enters the first compartment of the multiple spray rinse system where it drips for 2 to 3 seconds. The rack then travels horizontally across the 30 foot shuttle at a rate of approximately 6 in/sec before vertically exiting the rinse system at the far end of the third compartment.

The first compartment of the rinse system (see Figure 1) is approximately 12 ft. in length and is used as a drip chamber. In the second compartment (approximately 3-4 ft. in length), a recirculated rinse spray is applied to the boards followed by a deionized water spray rinse. Both curtain spray type rinses are delivered to the boards via jet nozzles. Each nozzle directs a 2 square-inch area spray onto the boards. These nozzles are used to impart high water pressure to a concentrated area, thereby providing a mechanism for removing water and nickel from within the holes in the boards as well as from the surface of the boards. Prior NCR development data had shown that after 10 seconds of dripping, a large proportion of the residual dragout remained in the holes, and that use of the jet nozzles greatly enhanced metal removal efficiency.

The total recirculated rinsewater flow in the second compartment is approximately 21 gph and is applied to the boards through 17 spray nozzles. A chemical resistant pump transfers the rinsewater from the bottom of the compartment through the nozzles and onto the boards. Approximately 10 gph of deionized water are also applied to the boards through the 10 remaining spray nozzles in this compartment. The use of a programmable timer ensures that the recirculated and deionized water sprays are only activated for a period of approximately 23 seconds when the rack passes through this compartment of the shuttle.

Five spray bars are located in the first 3 feet of the third compartment and require approximately the same flows of recirculated rinsewater and deionized water as described for the second compartment. After the boards pass through the spray rinses, the rack travels to the end of this compartment where it remains stationary for a short period of time before proceeding to an overflow rinse, or an additional plating bath, depending on the specific process requirements.

A minimum of three pumps are used to incorporate recycle capabilities into the design of the spray rinse system. This provides the rinse system with not only the potential for improved rinse efficiency but also the ability to conserve and reuse process materials. One pump is used to transfer liquid from the bottom of the first compartment back to the nickel bath. This pump can also be used to transfer liquid from the storage tank (see Figure 1) back to the bath, and to transfer liquid from the storage tank to waste treatment when necessary.

As mentioned earlier, a second pump is used to recirculate rinsewater from the bottom of the second compartment onto the boards. When the level in this compartment reaches approximately 6 inches, a solenoid valve automatically opens allowing the rinsewater to be transferred to a 100 gallon head tank. On a routine basis rinsewater from the head tank is gravity drained to the nickel bath for make-up water. The head tank incorporates an overflow valve allowing excess rinsewater to be transfered to the storage tank if required. A third pump is used to recirculate the rinsewater in the third compartment and transfer excess water to the storage tank when required. When a sufficient quantity of

rinsewater has accumulated in the storage tank, it is transferred batchwise to waste treatment where it is treated and filtered to isolate and recover the nickel sludge.

SAMPLING AND ANALYSIS

The efficiency of the spray rinsing system was evaluated by measuring the amount of nickel remaining on the printed circuit boards at several points in the rinsing operation. The amount of nickel on each board was determined by removing the board from the rack and placing the board in a reinforced, self-sealing, clear, polyethylene bag to which 400 milliliters of deionized water had been added. To effect equilibrium, the bag and its contents were then vigorously shaken in a uniform and consistent pattern to assure removal of the nickel from the surface of the board as well as from within the holes in the board. The resulting solution was then analyzed by atomic absorption spectroscopy. Laboratory evaluation of this sampling technique resulted in a precision of ±1%. In actual sampling, the precision of this technique was between five and ten percent.

The boards were sampled and the rinse efficiency determined for the second and third compartments of the spray rinse system. In addition, boards were sampled after the first recycle spray and the second recycle spray to determine the contribution of each deionized and recycle spray in the second and third compartments. Residual nickel was also determined for boards rinsed by only one deionized spray, by two successive deionized sprays, and finally by two successive recycle sprays. The amount of nickel per board remaining after each sampling point was then calculated. The percent of total and residual nickel removed after each rinsing sequence was also determined and compared to that of the previously used Napco shuttle dip rinse system.

The amount of nickel dragout attributed to the rack was determined by running the empty rack from the bath through the first deionized spray and measuring the increase in nickel concentration in the bottom of the spray compartment. In addition, samples of the solution in the bottom of each compartment were analyzed to determine the concentration of nickel in the recycle sprays and the concentration of solutions being recycled to the nickel plating bath.

All of the samples were preserved by acidifying to a pH less than two with concentrated nitric acid and were split between EPA and NCR. A Perkin-Elmer 4000 atomic absorption spectrophotometer (AAS) was used by EPA to analyze the samples in accordance with standard analytical methodology (7). A Perkin-Elmer 203 AAS was used by NCR for their analyses. Quality control check standards were obtained from EPA's Environmental Monitoring and Support Laboratory and analyzed by both EPA and NCR to ensure that both instruments were operating properly, and to identify and correct any intra-laboratory inconsistencies concerning sample preparation and/or analysis. Spikes and replicate analyses were also done to check for accuracy and precision and to identify the presence of any matrix effects associated with sample preparation or measurement. Data were then combined and statistically evaluated. A significance level of 0.05 was used to determine the acceptance or rejection of outlying observations of the combined data in accordance with Dixon's test for detecting outlying observations (8).

Rinse Efficiency

The rinse efficiency of the spray rinse system was determined and compared to that of the Napco shuttle dip rinse system previously used. By measuring the amount of nickel on the printed circuit boards after various stages in the spray rinsing system, and measuring the nickel concentration of the plating bath, the dragout volume and nickel dragout per board were calculated after each rinsing sequence. Metal removal at various stations in the spray rinse system was determined and data are presented in Table 1.

The first column in Table 1 shows the residual grams of nickel metal remaining per board after each rinsing sequence. In column two the percentage of the original amount of metal removed from the board at a specific point in the system is shown. Likewise, the percentage of the residual metal removed at a specific location was calculated and is shown in column three. Column four shows the accumulated percentage of metal removed at a specific location.

Results showed that of the 1.29g of nickel remaining on the board after dripping in the first compartment of the rinse system, 95.5 percent was removed by the first recycle spray, and an additional 2.95 percent was removed by the first deionized spray in the second compartment. Approximately 0.78 percent and 0.38 percent were removed by the third compartment recycle and deionized sprays, respectively. The rinse efficiency of the second compartment was found to be 98.4 percent [(1.29g - 0.02g)/1.29g x 100], while that of the third compartment was calculated as 75 percent [(0.02g - 0.005g)/0.02g x 100].

Although these two compartments have the same rinsing pattern and flow rates, the lower efficiency of the third compartment was not unexpected. Metal removal in the second compartment was suspected to be easier than that in the third compartment, and was primarily from the surface of the board and also from within the holes in the board. Since the board surface was covered with the resist film, liquid droplets were more easily removed than liquid from the inside surface of the drilled holes where no film was present. Due in part to these surface differences, additional metal removal in the third compartment was expected to be more difficult since it primarily required removal of the residual material from within the holes. Removal in this compartment was further hindered by the nickel reaction occurring on the board's surface. A characteristic of this plating process was the quick drying action of the metal on the surface of the boards. Theoretically, this reaction prevented total removal of the metal by the rinse due to solubility and time limitations. This was also confirmed by the decreasing residual removal data shown in column three of Table 1.

The second section of Table 1 compares the effect of deionized spray sequences. The percentage of total nickel removed per board with only one deionized spray was approximately 0.4 percent greater than that with one recycle spray. The data further show that although the incremental difference between one and two passes in front of a deionized spray was only a 3.9 percent increase in metal removal, the second pass removed over 70 percent of the residual metal on the board.

The data provided by NCR and reported in the bottom of Table 1 show that the previously used dip rinse system removed 99.4 percent of the metal via the 3.5 gpm Napco shuttle, and an additional 0.40 percent in the 1.5 gpm overflow rinse. In summary, the data show that the

shuttle, in combination with the follow-up rinse removed 99.8 percent of the nickel using 5 gpm of water. This compares to 99.6 percent metal removal achieved by the spray rinse system with only 0.35 gpm of water. Overall, this equates to comparable rinsing efficiency by the spray rinse system with a 93 percent reduction in the total amount of water used.

Materials Balance

A materials balance for the spray rinse system was performed to determine the quantity of nickel recovered for reuse in the nickel bath. During the period from August 22, 1983 through November 4, 1983 a record was kept of all materials leaving the spray rinse system, as shown in Table 2.

The balance included the quantities of solution and the concentrations of nickel in all liquid transfers. These included transfers (1) from the first compartment (drip chamber) to the bath, (2) from the second compartment (first set of recycle and deionized spray rinses) to the head tank and then to the bath, (3) from the third compartment (second set of recycle and deionized spray rinses) to the storage tank and then to the bath and (4) from the storage tank batchwise to waste treatment. Not included in the balance were allowances for nickel dragout from the spray rinse system (to a subsequent bath), water dragout from the spray rinse system (to a subsequent bath), or loses due to evaporation.

Overall, the balance showed that approximately 94 percent of the nickel entering the spray rinse system was recycled back to the bath for reuse. Approximately 4 percent was directed to waste treatment, and 2 percent was lost through dragout and losses within the system (lines, filters, pumps, etc.)

In comparison, approximately 98 percent (5.67#/day) of the nickel entering the rinse system was directed to waste treatment when the dip rinse system was used. Implementation of the spray rinse system, therefore, resulted in a 96 percent reduction in the amount of nickel requiring treatment and/or disposal. On average, 39 percent (178/460* gpd, Table 3) of the water inflow to the rinse system (0.35 gpm or 460 gpd) was recycled and reused for bath make-up water. Approximately 46 percent (211/460 gpd, Table 3) of the water inflow was sent to waste treatment. Based on mass balance calculations, it was estimated that 71 gpd were lost through evaporation and drag-out from the spray rinse system. In conclusion, during the 53 operating day period, a total of 11,206 gallons of wastewater, or an average of 211 gpd, were directed to waste treatment as a result of the implementation of the spray rinse system.

In comparison, the dip rinse system would have required approximately 6600 gpd of water (5.0 gpm, Table 1) over a comparable time period. Assuming estimated evaporation and dragout losses of 40 gpd, approximately 6560 gpd would have been directed to waste treatment. Therefore, there was a 97 percent reduction in the amount of water sent to waste treatment as a result of the implementation of the spray rinse system.

*based on a 22 hour workday, 260 days of operation/year

Economic Analysis

This study indicated that utilization of the spray rinsing system in place of the Napco shuttle dip rinsing operation reduced operating costs without sacrificing rinse efficiency. As reported earlier, water usage decreased 93 percent. Approximately 94 percent of the nickel metal and 39 percent of the water inflow to the spray rinse system (see Table 3) was recycled back to the bath. As expected, these reductions translate into substantial economic savings as shown in Tables 3 and 4. Overall, implementation of the new system resulted in an estimated payback period of less than one-and-a-half years.

Table 4 provides a comparison of the costs associated with the two rinse systems. All calculations were based on a work standard of 22 hours/day and 260 days of operation/year. The water usage requirements were calculated based on the flow rates given for each system. From the data reported in Table 2 (which has been repeatedly confirmed since the evaluation periods) the quantity of nickel metal not recovered per year was determined for each system. In addition, water, treatment and disposal costs were calculated based on local charges. Sludge disposal costs were determined based on a drum loading of 65 pounds and rounded to the nearest drum. The cost of plating chemicals not recovered was calculated based on pounds of nickel used per year. Additional costs, such as filter cartridges for the deionized water unit were also considered and reported as actual costs. The annual savings in each cost category were then determined and used in an economic analysis of the spray system as shown in Table 5. It is noteworthy that over 60 percent of the annual savings resulted from the recycling of plating chemicals alone.

The installed cost of the spray rinse was $8300. This figure included all materials and in-house labor to alter the shuttle and install the spray system. Of this amount, shuttle alteration was 12 percent, the spray system 18 percent, the pump and recovery system 52 percent, and the automatic panel control system was 18 percent. It is recognized that the installed cost of this system is high, however this particular unit was built as a prototype to develop design criteria for curtain spray, full cone spray, and other rinsing systems. A unit designed specifically to isolate and recover metal in this type of plating application could be built and installed for a fraction of the cost of this prototype unit.

Annual operating costs, fixed costs, and savings were calculated based on the data presented, and are itemized in Table 5. Overall, installation of the new rinse system resulted in an initial positive cash flow, and a net after tax savings of over $4,900 which equates to a payback period for the system of less than 1.5 years.

CONCLUSION

The mutiple spray rinsing system has been in operation for approximately a year and a half, and to date (August, 1984) no major problems have been encountered. Performance data consistent with that presented has been routinely achieved. Additional testing is underway to evaluate other types of sprays, different spraying patterns, and rinsing sequences.

In summary, the installation of this spray rinsing system has proven to be both an environmental and economic success. The simple design and very low maintenance associated with the system render it attrac-

tive to other electroplating processes as well as other rinsing processes outside the metal finishing industry. Since the inceptions of this project, the recent installation of similar spray rinse systems has been brought to the attention of the authors. Reported applications have included various types of electroplating processes and have eliminated the need for otherwise more expensive "black box" technologies.

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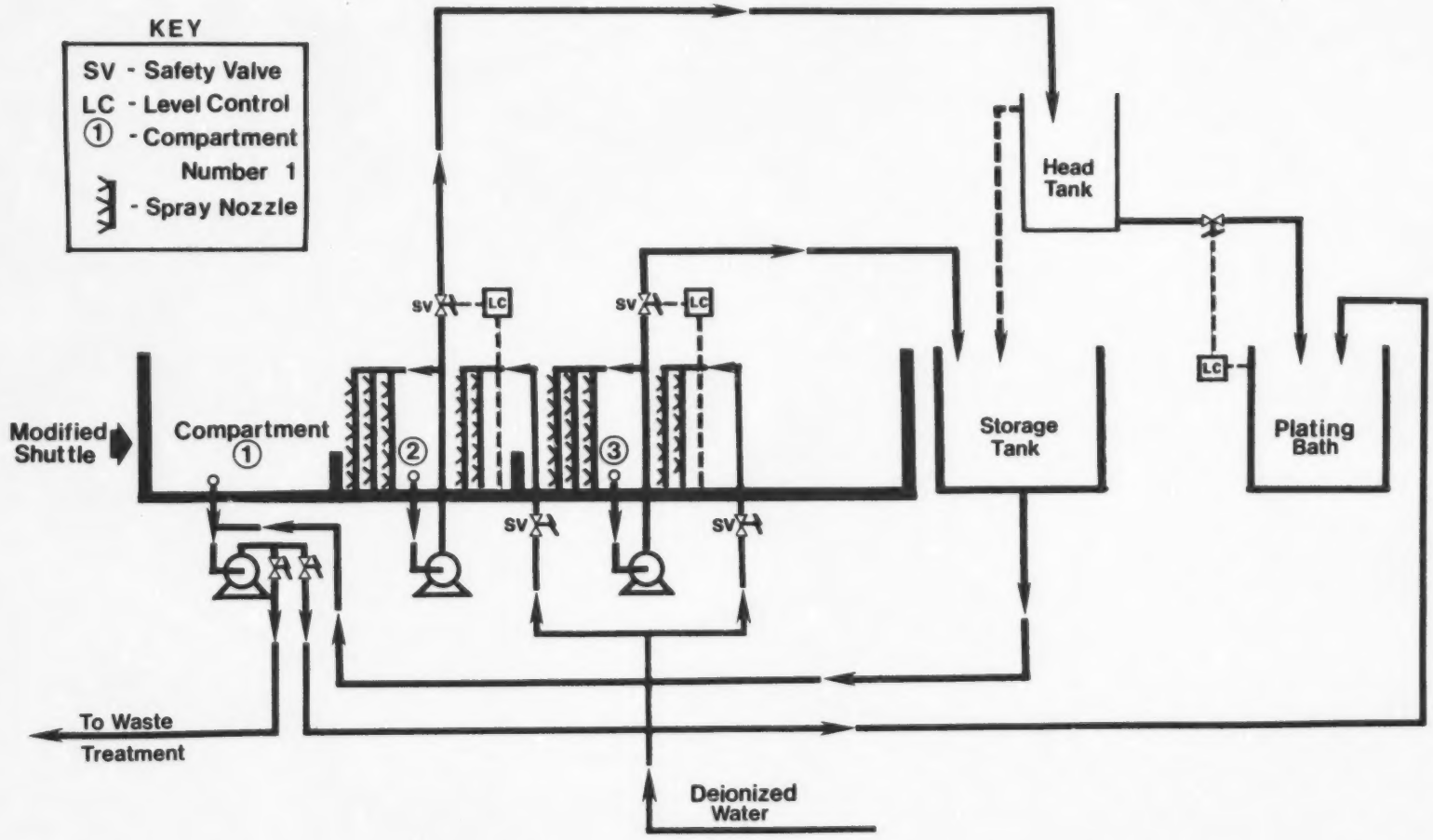

FIGURE 1: NCR NICKEL RECYCLE/RECOVERY SYSTEM (NOT DRAWN TO SCALE)

Table 1: Evaluation of Metal Removal Efficiency at Various Stations in the Spray Rinse System and Napco Shuttle Dip Rinse System

Rinsing Sequence	Nickel Remaining per Board After Rinsing Sequence (g)	Amount of Nickel Removed per Station as Percentage of Total (%)	of Residual (%)	Accumulation (%)
Drip only	1.29	-	-	-
Drip + First Recycle Spray	0.058	95.5	95.5	95.5
Drip + First Recycle Spray + First DI* Spray	0.020	2.9	66.0	98.5
Drip + First Recycle Spray + First DI Spray + Second Recycle Spray	0.010	0.78	50.0	99.2
Drip + First Recycle Spray + First DI Spray + Second Recycle Spray + Second DI Spray	0.005	0.38	50.0	99.6
Drip + First DI Spray	0.053	95.9	-	
Drip + First DI Spray + Second DI Spray	0.015	99.8	71.7	
Napco Shuttle Dip Rinse System				
3.5 gpm Shuttle	0.0081	99.4	99.4	99.4
1.5 gpm Overflow Rinse	0.0033	0.40	59.3	99.8

*Deionized

Table 2: Materials Leaving Spray Rinse System During Test Period[a]

Period		No. of Operating	Recycled to Bath				Treated at Waste Treatment			
Dates			Nickel		Water		Nickel		Water	
From	To	Days	lbs.	%	gals.	%	lbs.	%	gals	%
8/22/83	9/27/83	26	128	94	4,540	48	8.1	6	4,972	52
9/28/83	11/4/83	27	156	97	4,897	44	4.1	3	6,234	56
Daily Average		-	5.4 #/d	95	178gpd	46	0.23 #/d	5	211gpd	54

(a) Not Included in the Above
1. Evaporation Loses and Water Dragout (Amounting to approx. 71 gpd)
2. Nickel Dragout (Residual)

Table 3: Material Balance for the Two Rinsing System(a)

Rinse System	SYSTEM INFLOWS: Dragin From Bath Nickel (#/d)	SYSTEM INFLOWS: Water In-flow (gpd)	SYSTEM OUTFLOWS: Recycled To Bath Nickel (#/d)	Nickel (%)	Water (gpd)	Water (%)	Directed to Waste Treatment Nickel (#/d)	Nickel (%)	Water (gpd)	Water (%)	Losses (Evaporation, Dragout, etc.) Nickel (#/d)	Nickel (%)	Water (gpd)	Water (%)
Dip Rinse System	5.77	6600	0	0	0	0	5.67	98	6560	99	0.10	2	40	1
Spray Rinse System	5.77	460	5.4	94	178	39	0.23	4	211	46	0.14	2	71	15

(a)Based on data from 53 operating day test period (Table 2)

Table 4: Comparison of Material and Cost Requirements For Dip and Spray Rinse Systems

	Dip Rinse System	Spray Rinse System	Annual Savings
Material Requirements			
Total Flow Rate (gal/min)	5.0	0.35[a]	
Water Usage Requirement(1000 gal/yr)[b]			
City Water	1200	0	
Deionized Water	515	120	
Plating Chemicals Lost (# Nickel Metal/yr)	1500	96	
Costs[c]			
Water ($/Yr) City @ $1.00/1000 gal. Deionized @ $2.00/1000 gal.	$2,230	$240	$1,990
Wastewater Treatment ($/Yr) @ $0.75/1000 gal.	1,286[d]	55[e]	1,231
Sludge Disposal ($/Yr) @ $61.00/drum	1,403	122	1,281
Plating Chemicals Lost ($/Yr) @ $5.62/lb Nickel Metal	8,430	540	7,890
Other ($/Yr) (i.e., filter cartridges)	-	170	(170)

[a] reflects 0.38 gpm/nozzle due to pressure drop across filters
[b] based on full manufacturing capacity
[c] all costs are in 1983 dollars
[d] ignores evaporation and drag-out losses (less than 1%)
[e] assumes 46% of water usage requirement was directed to waste treatment (see Table 3)

Table 5: Economic Analysis of Spray Rinse System

Installed Cost ($/Yr):	
Equipment (pumps, piping, control box, liner, etc.)	$ 4,800
Installation	3,500
	$ 8,300
Annual Operating Costs ($/Yr):	
Labor Maintenance	$ 500
Materials (filter cartridges, plating chemicals)	653
Utilities (energy, water)	440
Wastewater Treatment	50
Sludge Disposal	90
Plant Overhead	200
	$ 1,933
Annual Fixed Costs ($/Yr):	
Depreciation (10% of investment)	$ 830
Taxes & Insurance (1% of investment)	83
	$ 913
Annual Savings ($/Yr):	
Water	$ 1,990
Wastewater Treatment	1,231
Sludge Disposal	1,281
Plating Chemicals	$ 7,890
	$12,392
Net Savings ($/Yr) = [Annual Savings - (Operating Costs + Fixed Costs)]	$ 9,546
Net Savings After Taxes ($/Yr), 48% Tax Rate	$ 4,964
Cash Flow ($/Yr) = (Net Savings After Taxes + Depreciation)	$ 5,794
Payback Period (yrs) = (Investment/Cash Flow)	1.43